

## Steel Structures and Bridges 2012

# Design of corrosion allowances on structures from weathering steel

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**Abstract**

The corrosion rate of the weathering steel is considerably lower than that of the standard carbon steel. In spite of this, possible effects of corrosion losses on reliable service of the structure throughout the designed service life should be considered when designing the structures. In practice, the effects of the expected corrosion losses are typically eliminated by corrosion allowances which are added to the thickness of the element calculated in static analyses. This paper introduces a new method used for calculation of corrosion allowances. The application of the procedure for calculation of corrosion allowances is explained using example of a bridge structure.

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**1. Introduction**

Weathering structural steel has been used for various outdoor load-carrying structures (even without anti-corrosion surface protection) in the world (U.S.A., Germany, Japan, South Korea, France, Switzerland, New Zealand...) as well as in the Czech Republic for about 40 years.

The corrosion rate of the weathering steel is considerably lower than that of the standard carbon steel. In spite of this, possible effects of corrosion losses on reliable service of the structure throughout the designed service life,  $T_d$ , should be considered when designing the structures. In practice, the effects of the expected corrosion losses are typically eliminated by corrosion allowances which are added to the thickness of the element calculated in static analyses.

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The corrosion allowance in foreign standards is typically derived from a single parameter - the classified corrosion aggressiveness of atmospheres [1]. Table 1 shows the recommended corrosion allowances for one exposed surface of construction and for the designed service life of  $T_d = 100$  years.

Table 1. Corrosion allowances for the designed service life pursuant to foreign regulations

Country	Corrosion allowance for the corrosion aggressiveness ranging from C2 to C4		
	C2	C3	C4
Germany	0.8 [mm]	1.2 [mm]	1.5 [mm]
United Kingdom	1.0 [mm]	1.0 [mm]	1.5 [mm]
Sweden	0.6 [mm]	1.2 [mm]	1.7 [mm]
Note: The corrosion allowances for Germany, United Kingdom and Sweden were taken from [2, 3], [4], and [5], respectively.			

Most structures designed from the weathering steel which were built in the Czech Republic have been inspected and assessed over the last years [13]. It follows from the inspections and corrosion tests that more parameters should be taken into account in order to determine more exactly the corrosion losses and subsequently corrosion allowances, the corrosion aggressiveness only being not enough for this. The new method, if compared with procedures described in [2 to 5], introduces several basic changes, in particular:

- The exposed surfaces are divided into three categories: directly wetted surfaces, indirectly wetted surfaces and surfaces in inside environment.
- The guiding value of corrosion loss is calculated on the basis of the current level of air pollution in the Czech Republic.
- The calculation of the design value of corrosion loss specifies clearly influences of the position and location of the surface in the structure.
- More attention is paid to increased corrosion stress of the structure, if any, caused by neglected maintenance.
- A consistent difference is made between the different quantities: the corrosion loss and the corrosion allowance.
- The minimum corrosion allowance depends not only on the designed corrosion loss, but also on the thickness of the element, on limit rolling tolerances and on static use of the element under assessment.

## 2. Corrosion allowances

The new developed method for calculation of corrosion losses is described in [6]. The method takes into account actual environmental conditions in the location of the structure, exposure conditions, position and location of the surface in the structure, influence of neglected maintenance and compliance with recommended structural principles.

Because corrosion losses in the thickness of the structural weathering steel elements might be rather extensive and might reduce reliability of the structure in case of limit state conditions, it is essential to add a reasonable corrosion allowance to the initial nominal thickness of the load-carrying capacity.

The minimum corrosion allowance for the thickness of the structural element is calculated as follows:

$$\Delta t_{\min} = t_{d,\min} + K_{Td1} + K_{Td2} - t_{\text{nom}} - k_v, \quad \text{but } \Delta t_{\min} \geq 0 \quad (1)$$

where  $t_{d,min}$  is the minimum thickness of the structural element which is satisfactory for the decisive limit state;  $K_{Td1}$  is the design value of corrosion loss of the surface 1;  $K_{Td2}$  is the design value of corrosion loss of the surface 2;  $t_{nom}$  is the nominal thickness of the element and  $k_v$  is the value depending on the thickness and class of the hot rolled steel plate (see Table 2).

Table 2. Values of  $k_v$  for calculation of the corrosion allowance

Nominal thickness	classification depending on nominal thickness tolerances pursuant to EN 10029 [11]			
	class A	class B	class C	class D
	$k_v$ ( $\mu\text{m}$ )			
$5 \text{ mm} < t \leq 8 \text{ mm}$	50	150	450	-150
$8 \text{ mm} < t \leq 15 \text{ mm}$	100	250	600	-250
$15 \text{ mm} < t \leq 25 \text{ mm}$	150	450	750	-200
$25 \text{ mm} < t \leq 40 \text{ mm}$	250	750	1050	-100
$t \geq 40 \text{ mm}$	400	1100	1400	100
Note: Values of $k_v$ in the table are derived from the two assumptions given below: a) Weakening the element by corrosion by 1% of the thickness does not significantly affect reliability of the structure [7, 8]. b) Influence of lower (negative) limit rolling tolerances in class A (being the typically supplied class of the limit rolling deviations) onto reliability of the structure is considered in the partial factor for material property, $\gamma_M$ , in accordance with [9]. If the difference between class A and class B/C (for more stringent limit values of the tolerances) is taken, this covers the corrosion allowance, without influencing reliability of the structure (effects of various tolerances on reliability of the structure are described in [10]).				

It follows from (1) that the nominal thickness of the structural elements should be increased by the positive value of the corrosion allowance,  $\Delta t \geq \Delta t_{min}$ , in particular, in following cases:

- in cross-sections of the structure which are most loaded and best used, in terms of strength;
- in cross-sections which are most jeopardised in terms of corrosion (such as complex structural details, places affected by leaking water or surfaces jeopardised by salt solutions during winter maintenance of bridges).

In remaining parts of the structure, the calculated corrosion allowance is, as a rule, negative. In those parts it is, typically, useless and uneconomical to increase the nominal thickness of the structural elements. It does not have any sense either to evaluate and provide the corrosion allowances for the structural elements with the nominal thickness being equal to, or greater then, 50 mm because the corrosion allowances influence the reliable function of the thick-wall elements little only. Extensive studies conducted in Switzerland proved that in Switzerland it is not necessary to provide the corrosion allowance in addition to the thickness of standard structural elements in bridge structures [11].

### 3. Example – calculating the corrosion allowance

The chapter below gives an example of calculation of the corrosion losses and necessary corrosion allowances for the bridge structure (the calculation is carried out for the web and the upper/bottom flange of the main girder). This road bridge is located on the M1 motorway (Černovická terasa, Brno, Czech Republic). See Figures 1 and 2. The bridge superstructure is a composite steel and concrete continuous beam with five spans and the upper bridge deck. The load-carrying steel structure is made of weathering steel, S355J2W. For details about the bridge structure see [12].

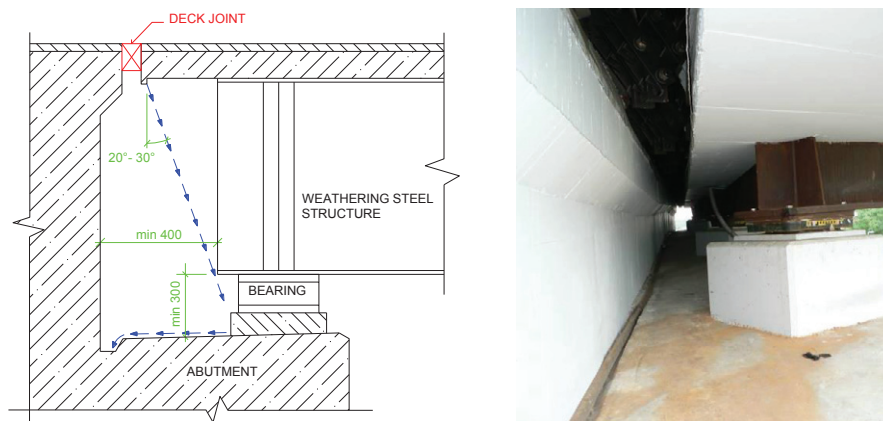


Fig. 1. Acceptable completion of the bridge superstructure next to the abutment (no corrosion treatment is necessary): left – recommended dimensions, right – road bridge on the M1 Motorway (Černovická terasa, Brno, Czech Republic, built 2005)

The guiding value of corrosion loss for the 100 year designed service life [6]:

$$K_T = 230 \mu\text{m} \text{ (taken from the map of the guiding values of corrosion loss)}$$

The design value of corrosion loss [6]:

$$K_{Td} = K_T \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \text{ (the general formula for calculation of the design value)}$$

$$\alpha_1 = 1,20 \text{ (steel S355J2W)}$$

$$\alpha_2 = 1,00 \text{ (the web of the main girder which is not affected by leaking water – see Fig. 1)}$$

$$\alpha_3 = 1,10 \text{ (the upper and bottom flange of the main girder are not affected by leaking water – see Fig. 1)}$$

$$\alpha_4 = 0,80 \text{ (sufficiently ventilated and indirectly wetted surfaces under the reinforced concrete deck)}$$

$$\alpha_4 = 1,00 \text{ (compliance with structural principles [6]; the structure can be accessed for maintenance)}$$

$$\text{Web of the main girder: } K_{Td} = K_T \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 = 230 \cdot 1,20 \cdot 1,00 \cdot 0,80 \cdot 1,00 = 221 \mu\text{m}$$

$$\text{Upper and bottom flanges: } K_{Td} = K_T \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 = 230 \cdot 1,20 \cdot 1,10 \cdot 0,80 \cdot 1,00 = 243 \mu\text{m}$$



Fig. 2. Road bridge on the M1 Motorway (Černovická terasa, Brno, Czech Republic, built 2005)

Calculation of the corrosion allowances [6]:

$$\Delta t_{\min} = t_{d,\min} + K_{Td1} + K_{Td2} - t_{\text{nom}} - k_v \quad (\text{the general formula for calculation of the corrosion allowance})$$

Web of the main girder (the required class of rolling tolerances of the supplied plates is B; the web thickness of the main girder is between 15 and 25 mm):

$$k_v = 450 \mu\text{m}$$

$$\Delta t_{\min} = (t_{d,\min} - t_{\text{nom}}) + K_{Td1} + K_{Td2} - k_v = (t_{d,\min} - t_{\text{nom}}) + 221 + 221 - 450 = (t_{d,\min} - t_{\text{nom}}) - 8 \mu\text{m}$$

The bottom flange of the main girder (the required class of rolling tolerances of the supplied plates is B; the web thickness of the main girder is between 25 and 40 mm):

$$k_v = 750 \mu\text{m}$$

$$\Delta t_{\min} = (t_{d,\min} - t_{\text{nom}}) + K_{Td1} + K_{Td2} - k_v = (t_{d,\min} - t_{\text{nom}}) + 243 + 243 - 750 = (t_{d,\min} - t_{\text{nom}}) - 234 \mu\text{m}$$

The upper flange of the main girder (the required class of rolling tolerances of the supplied plates is B; the web thickness of the main girder is between 25 and 40 mm):

$$k_v = 750 \mu\text{m}$$

$$\Delta t_{\min} = (t_{d,\min} - t_{\text{nom}}) + K_{Td1} - k_v = (t_{d,\min} - t_{\text{nom}}) + 243 - 750 = (t_{d,\min} - t_{\text{nom}}) - 507 \mu\text{m}$$

Assessment of the calculation:

It follows from the calculation above that no corrosion allowances are necessary for the elements of the bridge superstructure even if the cross-section of the main girder is fully used in terms of statics (the necessary minimum thickness of the element which is compliant at the decisive limit condition,  $t_{d,\min}$ , is equal to the nominal thickness of the element,  $t_{\text{nom}}$ ). The design values of corrosion loss are sufficiently covered by the more stringent requirements which apply to the negative rolling tolerance in the B class of the limit rolling deviations.

**4. Conclusion**

This paper describes methods used for calculation of the corrosion allowance to be added to the thickness of elements made of the weathering steel. The methods are based on new findings gained during the project work [13]. Calculation of the corrosion losses and, in turn, corrosion allowance, is among specific steps typically for designs of structures made of the weathering steel. For a comprehensive description of steps used when designing the structures made of the weathering steel - see the new directive [6] which is the main outcome of the project [13].

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